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A Brief Review of Econophysics

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ABSTRACT

Econophysics is an interdisciplinary branch which is related with the study of the dynamical behavior of financial and economic markets. The conventional economic approaches are generally based upon static assumptions. They explore little about the dynamical behavior of the systems. Since such systems consist of a large number of agents interacting nonlinearly, they exhibit the properties of a complex system. Therefore the tools of statistical physics and nonlinear dynamics has been proved to be very useful the underlying dynamics of the system. In this paper we introduce the concept of econophysics, a neologism that denotes the activities of Physicists who are working on economic problems to test a variety of new conceptual approaches deriving from the physical science and review the chronological developments in the discipline.

Keywords: Econophysics, Quantitative finance.

1. INTRODUCTION

Econophysics is an interdisciplinary field, applying theories and methods originally developed by physicists in order to solve problems in economics[1-3]. Its application to the study of financial markets has also been termed statistical finance referring to its roots in statistical physics. It is a new area developed recently by the cooperation between economists, mathematicians and physicists. It applies idea, method and models in Statistical Physics and nonlinear dynamics to analyze data from economical phenomena[4]. Over the past couple of decades, a large number of physicists have started exploring problems which fall in the domain of economic science.

The common themes that are addressed by the research of most of these groups have resulted in coining a new term "econophysics" as a collective name for this venture. Bringing together the techniques of statistical physics and nonlinear dynamics to study complex systems along with the ability

to analyze large volumes of data with sophisticated statistical techniques, the discoveries made in this field have already attracted the attention of mainstream physicists and economists.

Work on “Econophysics” was started by several physicists working in the subfield of statistical mechanics. Unsatisfied with the traditional oversimplified approaches of economists for the sake of soluble theoretical models over agreement with empirical data – these physicists applied tools and methods from physics. They first tried to match financial data sets, and then to explain more general economic phenomena. Sudden availability of large amounts of financial data, starting in the 1980s made the life simple for econophysicists. As the traditional methods of analysis were insufficient - standard economic methods dealt with homogeneous agents and equilibrium, while many of the more interesting phenomena in financial markets fundamentally depended on heterogeneous agents and far-from-equilibrium situations.

Many physicists working in this field do believe that physics has a novel perspective to contribute to the traditional way of studying economics. However the majority of mainstream economists have been dismissive until very recently of the claim that physics can have something significant to contribute to the field. Physics is seen by them to be primarily a study of interactions between simple elements, while economics deals exclusively with rational agents, able to formulate complex strategies to maximize their individual utilities (or welfare).

The recent worldwide crisis of 2008 has now led to some voices from within the field of economics itself declaring that new foundations for the discipline are required. The economists Lux and Westerhoffin[4] have suggested that econophysics may provide such an alternative theoretical framework for rebuilding economics. As Lux and other economists have pointed out the systemic failure of the standard model of economics arises from its implicit view that markets and economies are inherently stable. Similar sentiments have been expressed by the econophysicist Bouchaud[2-3].

The study of a wide variety of complex systems, e.g., from cellular networks to the internet and biological ecosystems, using the tools of statistical physics and nonlinear dynamics has led to the understanding that inherent instabilities in dynamics often accompanies increasing complexity[6-8].

Since the mid of twentieth century, economics has modeled itself more on mathematics than any of the natural sciences. The decisions made by the IMF and World Bank which affect millions of lives are made on the basis of theoretical models which have never been subjected to empirical verification. In view of this, some scientists suggested that econophysics may provide an alternative theoretical framework for a new economic science.

There has been a long association between physics and economics. The pioneers of economics have borrowed almost term by term the physics to set up their theoretical framework. Paul Samuelson, the second Nobel laureate in economics tried to reformulate economics as an empirically grounded science modeled on physics in his book Foundations of Economic Analysis. The use of classical

dynamical concepts such as stability and equilibrium has been used in the context of economics by Vilfredo Pareto. Economist Bill Philips constructed a hydraulic simulator for the national economy that modeled the flow of money in society through the flow of colored water. The macroeconomic concepts were mapped to the movement of fluids to demonstrate that the economy is as much a subject of physical inquiry as other more traditional subjects in physics.

Around the mid of the 20th century the focus of economists shifted towards proving existence and uniqueness of equilibrium solutions. A parallel development in their approach was the use of mathematical game theory to economics. The game theory proved to be ideal for studying how selfish individuals constantly devise strategies to get the better of other individuals in their continuing endeavor to maximize individual utilities. The concept of bounded rationality was developed to take into account practical constraints that may prevent the system from reaching the optimal equilibrium even when it exists.

A meeting between physicists and economists jointly organized by Philip Anderson jointly organized with Kenneth Arrow at the Santa Fe Institute in the late 1980s resulted in several early attempts by physicists to apply the recently developed tools in non-equilibrium statistical mechanics and nonlinear dynamics to the economic arena[4].

Currently there are many groups in physics departments around the world who are working on problems related to economics, ranging from Japan to Brazil, and from Ireland to Israel. While the problems they work on are diverse, ranging from issues connected with price fluctuations in the stock market to models for explaining the observed economic inequality in society.

CHRONOLOGY OF ECONOPHYSICS

When physics started to develop, around the time of Galileo Galilei (1564-1642), the modern science was in nascent stage. The developments in mathematics, astronomical studies in particular, had a deep impact on the development of physics. Mathematics has remained at the core of physics since then. The rest of "main stream" sciences, like chemistry, biology, etc., have all tried to obtain inspiration from, utilize, and compare with physics since that time. However the development in the social sciences started much later. However the physicists' interest in the social sciences is not new, it sates back to around 1700 when Daniel Bernoulli proposed the idea of utility-based preferences. One of the founders of neoclassical economic theory, Irving Fisher, was originally trained under the renowned physicist, Josiah Willard Gibbs. Likewise, Jan Tinbergen, who won the first Nobel Prize in economics in 1969 for having developed and applied dynamic models for the analysis of economic processes, studied physics with Paul Ehrenfest at Leiden University. Following are some of the pioneers of the field:

Adam Smith

Adam Smith was the first to formulate economic science. His model is based on the concept of a truly many-body system of selfish agents, each having no idea

of charity towards its fellow neighbors, or having no foresight (views very local in space and time), can reach an equilibrium where the economy as a whole is most efficient; leading to the best acceptable price for each commodity. This mechanism of the market to evolve towards the efficient is analogous to the demonstration of the "self-organization" mechanism in physics or chemistry of many-body systems, where each constituent cell or automata follows local dynamical rules and yet the collective system evolves towards a globally "organized" pattern.

Leon Walras to Alfred Marshal

Leon Walras, Alfred Marshal and others proposed marginal utility theory of price and cooperative or coupled demand and supply equations. These formulations incorporated the marginal utility concept, utilizing the following coupled demand-supply equations. In these equations demand and supply functions were considered to be in general nonlinear. These formulations of economic science were not appreciated in their early days and had a temporary setback. The lack of acceptance was due to the fact that neither utility nor marginal utility is measurable and the formal solutions of these coupled nonlinear equations in many variables still remain elusive.

Vilfredo Pareto

Vilfredo Pareto observed that the number density P(m) of wealthy individuals in any society decreases rather slowly with their wealth or income m:

$P(m) \sim m^{-\alpha}$;

for very large m (very rich people), $2 < \alpha < 3$. At almost the same time, J. W. Gibbs put forth that the number density P(E) of particles (or microstates) with energy E in a thermodynamic ensemble in equilibrium at temperature T falls off much faster:

$P(E) \sim \exp[-E/T]$

This was by then rigorously established in physics.

Louis Bachelier

Louis Bachelier (1870-1946) modeled the speculative price fluctuations (a). over time r. using Gaussian statistics (for a random walk):

$P(\sigma) \sim \exp[-\sigma^2/\tau]$

This actually predated Albert Einstein's (1879-1955) random walk theory (1905) by five years.

John von Neumann

Mathematician John von Neumann was the first to attempt developing game theories for microeconomic behavior of partners in oligopolistic competitions (to take care of the strategy changes by agents, based on earlier performance).

Paul Samuelson

Paul Samuelson investigated the dynamic stabilities of the demand-supply equilibrium by formulating, following Newton's equations of motion in mechanics, dynamical equations.

Jan Tinbergen

Jan Tinbergen (1903-1994), a statistical physicist (student of Paul Ehrenfest of Leiden University) analyzed the business cycle statistics and initiated the formulation of econometrics. By this time, these formal developments in economics, with clear influence from other developed sciences (physics in particular), were becoming recognized. Tinbergen was the first recipient of the newly instituted Nobel Memorial Prize in Economics in 1969. The next year, the prize went to Samuelson.

Kenneth Arrow, George Stigler And John Nash

Kenneth Arrow developed the axiomatic foundations of utility (ranking) theory, and the solution of general equilibrium theory. George Stigler first performed Monte Carlo simulations of markets (similar to those of thermodynamic systems in physics). John Nash gave the proof of the existence of equilibrium solutions in strategic games. All were awarded the Nobel Prize in Economics in 1972, 1982, and 1994, respectively. Although the impact of developments in physics has had a clear impact on economics, it has become more explicit in the last twenty five years.

Benoit Mandelbrot

The developments leading to econophysics had their seed in several earlier observations. Important among them was the observation by Benoit Mandelbrot in 1963 that speculative fluctuations (in the cotton market for example) have a much slower rate of decay, compared to that suggested by the Gaussian statistics of Bachelier, and decreases following power-law statistics:

$$P(\sigma) \sim \sigma^{-\alpha}$$

with some robust exponent value (a) depending on the time scale of observations.

H. Eugene Stanley

Group of H. Eugene Stanley gave rise to econophysics as a distinct field, the term coined by Stanley in 1995, in Kolkata. Eugene Stanley, Rosario Mantegna and coworkers established firmly the power law form of the stock price fluctuation statistics in the late 1990s.

Bikas Chakraborti

Bikas Chakraborti et.al proposed a random saving gas model that can easily capture these features of the distribution function. The "savings" ingredient in the ideal-gas model required for obtaining the gamma function form of the otherwise ideal gas (Gibbs) distribution, was also discovered more than a decade earlier by John Angle.

Some other notable econophysicists are Dirk Helbing, János Kertész, Matteo Marsili, Joseph L. McCauley, Enrico Scalas, Didier Sornette, H. Eugene Stanley, Victor Yakovenko, Yi-Cheng Zhang, Anirban Chakrabort, Sitabhra Sinha etc.

CONCLUSION

The intensive involvements of physicists together with a few economists in this new phase of development, the

econophysics has nearly established itself as a popular research discipline in statistical physics. It provides a promising alternative to, and a more empirically based foundation for the study of economic phenomena than, the mainstream axiom-based mathematical economic theory. Many physics journals are publishing papers on such interdisciplinary fields. Reputed journals like Physica, European journal of physics etc. are few names among them. Currently, the almost regular meeting series on the topic include: ECONOPHYS-KOLKATA, APFA, Econophysics Colloquiums, ESHIA/ WEHIA, etc. Courses on econophysics are also now being offered in several universities, mostly in their physics departments. Physics department of Leiden University is running a graduate course in econophysics.

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